APPENDIX B

INTENTIONAL DESTRUCTIVE ACTS

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B.1 INTRODUCTION

This appendix provides an analysis of the potential public health consequences of scenarios involving intentional destructive acts, such as terrorism events, associated with alternatives analyzed in this Global Nuclear Energy Partnership (GNEP) Programmatic Environmental Impact Statement (PEIS). This appendix relies directly on the results of accident analyses presented in Appendix D for reactors and a nuclear fuel recycling center and on accident analyses presented in Appendix E for transportation of nuclear materials. However, unlike accident analysis, the analysis of intentional destructive acts provides an estimate of the potential consequences of such events, without attempting to estimate the frequency or probability that an intentional destructive act would be attempted or would succeed. This is because there is no accepted basis for estimating the frequency of intentional destructive acts, and all facilities and activities associated with alternatives analyzed in this PEIS would be protected by professional guard forces and other security measures to help prevent such attacks.

Similar to the accidents analyzed in Appendix D of this PEIS, if an intentional destructive act were to occur that involved the release of radioactive materials, workers, members of the public, and the environment would be at risk. Workers in the facility where the act occurs would be particularly vulnerable to the effects of the act because of their location. The offsite public and surrounding environment would also be at risk of exposure to the extent that meteorological conditions exist for the atmospheric dispersion of released hazardous materials.

Consequences of radiological releases were determined using the MELCOR (Methods for Estimation of Leakages and Consequences of Releases) Accident Consequence Code System, version 2 (MACCS2) computer code (Chanin and Young 1998). MACCS2 is a U.S. Department of Energy (DOE)/U.S. Nuclear Regulatory Commission (NRC)-sponsored computer code that has been widely used in support of probabilistic risk assessments for the nuclear power industry and in support of safety and *National Environmental Policy Act* (NEPA) documentation for facilities throughout the DOE complex.

DOE estimated radiological impacts at each of six generic representative sites. The sites were chosen to represent permutations of locations with small, medium and large surrounding populations together with meteorology representing large and small dispersion (atmospheric mixing). Impacts to three receptors were analyzed at each of these sites: 1) the maximally exposed offsite individual (MEI), assumed to be a distance of 3,020 feet (ft) (920 meters [m]) from the hypothesized release at each site; 2) the offsite population within 50 miles (mi) (80 kilometers [km]) of each site; and, 3) a noninvolved worker 328 ft (100 m) from the release. See Section D.1.6 for a further discussion of these generic sites.

The calculation of population consequences was performed by distributing the population as appropriate for the hypothetical site into a radial grid. Ten radial rings and 16 uniform direction sectors were used to calculate the collective dose to the offsite population. Starting at the distribution center, the radial rings were every mile up to 5 mi (8 km), a ring at 10 mi (16 km), and a ring every 10 mi (16 km) from 10 to 50 mi (16 to 80 km). Appendix D, Section D.1.5.1 provides details of the methodology used for radiological material release calculations.

B.2 DOMESTIC PROGRAMMATIC ALTERNATIVES

Based on the analysis in Appendix D, the accident type with the greatest potential impact for each reactor type and a nuclear fuel recycling center is used as the basis for the intentional destructive act analysis. This PEIS assumes that it could be possible for an intentional destructive act to produce similar consequences because no credit is given for steps to prevent such threats or mitigate the consequences. For all facilities, except the light water reactor (LWR), the unmitigated aircraft crash presents the highest potential consequences. For the low-enriched uranium (LEU) and MOX-U-Pu fueled LWR, an internally initiated event presents the highest potential consequences.

The unmitigated aircraft crash analyses take no credit for the reactor containment. A study performed for the Nuclear Energy Institute (NEI 2002) determined that a commercial aircraft is not capable of penetrating a reactor's containment. However, a variety of potential secondary effects, such as damage to interfacing systems, could result from an aircraft crash and lead to reduced containment effectiveness. Rather than attempting to assess a degree of containment degradation, Appendix D evaluated the aircraft crash both with intact containment and without containment. This appendix only addresses the unmitigated cases, where the containment is assumed to fail. Containment survival is not a function of the reactor type, so partial or full containment after an aircraft crash is assumed to affect all reactor technologies similarly.

B.2.1 No Action Alternative

The No Action Alternative involves the construction and operation of new and replacement LWRs. This intentional destructive act analysis assumes that these would be both existing LWRs and advanced LWRs (ALWR) fueled with conventional LEU. Impacts would be dependent on many factors, including the type of act, site characteristics, and the distribution of population in the surrounding environment.

LWRs typically used in the U.S. commercial industry are designed to withstand off-normal events that could be postulated to occur, and if unmitigated, could lead to damage of nuclear fuel and release of radioactivity. This reactor concept uses a "defense in depth" approach to design where multiple levels of protection are provided against the release of radioactive material. Protective measures include the use of independent safety systems, fault detection and correction, and multiple physical barriers to the release of radioactivity from an accident. These multiple barriers limit the potential of intentional destructive acts from occurring and limit the effects in the event that one does occur.

B.2.1.1 *Low Enriched Uranium Fueled Light Water Reactor*

The impact of potential accidents at LWRs utilizing LEU fuel was evaluated for the *Surplus Plutonium Disposition Environmental Impact Statement* (hereafter SPD EIS) (DOE 1999d). The SPD EIS evaluated accidents at three existing LWR sites utilizing conventional LWR LEU fuel.

Appendix D, Section D.2.3.1 shows the "Interfacing System Loss of Coolant Accident (Interfacing System LOCA)" is the highest consequence event for LWRs using LEU fuel. An "Interfacing System LOCA" could be caused by an intentional destructive act. Table B.2.1.1-1 presents the consequences for the LEU fueled LWR "Interfacing System LOCA." The results presented include estimates of the incremental latent cancer fatalities (LCFs) for each receptor class at the six generic sites.

TABLE B.2.1.1-1—*Potential Consequences – Intentional Destructive Acts for a Low Enriched Uranium Fueled Light Water Reactor*

Site	Offsite Population		MEI[a]		Noninvolved Worker[b]	
	Dose (person-rem)	LCFs[d]	Dose (rem)	LCFs[c]	Dose (rem)	LCFs[c]
Generic Site 1 [e]	$1x10^6$	900	$2x10^4$	1 [k]	$2x10^5$	1 [k]
Generic Site 2 [f]	$4x10^6$	2,000	$2x10^4$	1 [k]	$2x10^5$	1 [k]
Generic Site 3 [g]	$2x10^7$	$1x10^4$	$2x10^4$	1 [k]	$2x10^5$	1 [k]
Generic Site 4 [h]	$7x10^6$	4,000	$1x10^5$	1 [k]	$5x10^5$	1 [k]
Generic Site 5 [i]	$1x10^7$	8,000	$1x10^5$	1 [k]	$5x10^5$	1 [k]
Generic Site 6 [j]	$6x10^7$	$4x10^4$	$1x10^5$	1 [k]	$5x10^5$	1 [k]

[a] 3,020 ft (920 m) from the hypothesized release
[b] 328 ft (100 m) from the hypothesized release
[c] Increased likelihood of a latent cancer fatality, calculated using the factor of 6×10^{-4} LCFs per rem, doubled for receptors exposed to doses greater than 20 rem, and truncated at 1
[d] Increased number of latent cancer fatalities, calculated using the factor of 6×10^{-4} LCFs per person-rem
[e] Large atmospheric dispersion with a population of 304,000 within 50 mi (80 km) of the site
[f] Large atmospheric dispersion with a population of 1,660,000 within 50 mi (80 km) of the site
[g] Large atmospheric dispersion with a population of 8,230,000 within 50 mi (80 km) of the site
[h] Small atmospheric dispersion with a population of 304,000 within 50 mi (80 km) of the site
[i] Small atmospheric dispersion with a population of 1,660,000 within 50 mi (80 km) of the site
[j] Small atmospheric dispersion with a population of 8,230,000 within 50 mi (80 km) of the site
[k] Calculated radiation dose to this individual is estimated to result in acute health effects

Using the dose-to-risk conversion factor of 6×10^{-4} LCFs per person-rem the collective population dose is estimated to result in a range of 900 to $4x10^4$ additional LCFs depending on dispersion and population size and the potential of prompt fatalities. These consequences are consistent with the results of the NRC's *Severe Accident Risks: An Assessment for Five U.S. Nuclear Power Plants*, NUREG-1150 (NRC 1990) and the *Surplus Plutonium Disposition Final Environmental Impact Statement*, DOE/EIS-0283 (DOE 1999d) when differences in population and meteorology are considered. The higher consequences for this accident than for other reactors are the result of differences in reactor power levels and differences in assumed release parameters. These values represent an upper bound of expected consequences from any new reactor built at any likely location. For the MEI and the noninvolved worker, the calculated radiation dose to this individual is estimated to result in acute health effects (e.g., damage to the central nervous system and death).

B.2.1.2 *Low Enriched Uranium Fueled Advanced Light Water Reactor*

As discussed in Appendix D, Section D.2.1.2, DOE has previously analyzed accidents associated with ALWRs at a variety of locations in the *Final Programmatic Environmental Impact Statement for Tritium Supply and Recycling* (hereafter Tritium Supply and Recycling Final PEIS) (DOE 1995b) and that PEIS is the basis used for the accidents analyzed in Appendix D. For the ALWR, the highest consequence accident is an "Unmitigated Aircraft Crash" (Appendix D, Section D.2.1). The "Unmitigated Aircraft Crash" could also be initiated by an intentional destructive event, so it is also the highest consequence intentional destructive act for the ALWR. Table B.2.1.2-1 presents the accident consequences for the LEU fueled ALWR.

TABLE B.2.1.2-1—*Potential Consequences – Intentional Destructive Acts for a Low Enriched Uranium Fueled Advanced Light Water Reactor*

Site	Offsite Population		MEI[a]		Noninvolved Worker[b]	
	Dose (person-rem)	LCFs[d]	Dose (rem)	LCFs[c]	Dose (rem)	LCFs[c]
Generic Site 1 [e]	$2x10^5$	100	3,000	1 [k]	$3x10^4$	1 [k]
Generic Site 2 [f]	$5x10^5$	300	3,000	1 [k]	$3x10^4$	1 [k]
Generic Site 3 [g]	$2x10^6$	1,000	3,000	1 [k]	$3x10^4$	1 [k]
Generic Site 4 [h]	$1x10^6$	600	$2x10^4$	1 [k]	$2x10^5$	1 [k]
Generic Site 5 [i]	$2x10^6$	1,000	$2x10^4$	1 [k]	$2x10^5$	1 [k]
Generic Site 6 [j]	$8x10^6$	5,000	$2x10^4$	1 [k]	$2x10^5$	1 [k]

[a] 3,020 ft (920 m) from the hypothesized release
[b] 328 ft (100 m) from the hypothesized release
[c] Increased likelihood of a latent cancer fatality, calculated using the factor of 6×10^{-4} LCFs per rem, doubled for receptors exposed to doses greater than 20 rem, and truncated at 1
[d] Increased number of latent cancer fatalities, calculated using the factor of 6×10^{-4} LCFs per person-rem
[e] Large atmospheric dispersion with a population of 304,000 within 50 mi (80 km) of the site
[f] Large atmospheric dispersion with a population of 1,660,000 within 50 mi (80 km) of the site
[g] Large atmospheric dispersion with a population of 8,230,000 within 50 mi (80 km) of the site
[h] Small atmospheric dispersion with a population of 304,000 within 50 mi (80 km) of the site
[i] Small atmospheric dispersion with a population of 1,660,000 within 50 mi (80 km) of the site
[j] Small atmospheric dispersion with a population of 8,230,000 within 50 mi (80 km) of the site
[k] Calculated radiation dose to this individual is estimated to result in acute health effects

Using the dose-to-risk conversion factor of 6×10^{-4} LCFs per person-rem, the collective population dose is estimated to result in a range of 100 to 5,000 additional LCFs. For the MEI and noninvolved worker, the calculated radiation dose to this individual is estimated to result in acute health effects (e.g., damage to the central nervous system or death).

B.2.2 Fast Reactor Recycle Alternative

This section presents the impacts of potential intentional destructive acts associated with facilities under the Fast Reactor Recycle Alternative. This section is further sub-divided into the impacts of these events at two facilities: the nuclear fuel recycling center, and the advanced recycling reactor.

B.2.2.1 *Nuclear Fuel Recycling Center*

As described in Chapter 2 of this PEIS, the programmatic alternatives being considered involve a variety of open and closed fuel cycles. The closed fuel cycles would include spent nuclear fuel (SNF) separations, fuel fabrication, and waste management activities. Appendix D, Section D.2.2.1 concluded for the nuclear fuel recycling center that the impacts associated with the separations activities are more significant than those of the other activities and, based on this conclusion, this intentional destructive acts analysis focuses only on the separation activities. Separations activities are considered to represent a greater potential impact than the fuel fabrication and waste management activities because of the inventories, material forms, and hazards of the processes involved.

Rather than analyze many variations in separations technology, process steps, and equipment selection, this analysis is based on a separations design that is enveloping for the options being considered. The aqueous separations evaluation is based on consideration of the voloxidation step that produces a very fine powder, use of extraction columns, and vessels each sized for a full day of throughput. These design assumptions are considered enveloping for not only electrochemical separation, but also for variations in aqueous separations implementation. Therefore, the intentional destructive acts analysis results in this section for the nuclear fuel recycling center are expected to be at least as great as the consequences associated with any activities that may be used for any of the closed fuel cycle alternatives and options being considered.

Appendix D provides an analysis of facility accidents for the nuclear fuel recycling center. The highest consequence accident is an "Unmitigated Aircraft Crash," which could also be caused by an intentional destructive act. The results for the "Unmitigated Aircraft Crash" for the nuclear fuel recycling center are provided below in Table B.2.2.1-1.

TABLE B.2.2.1-1—*Potential Consequences – Intentional Destructive Acts at a Nuclear Fuel Recycling Center*

Site	Offsite Population		MEI[a]		Noninvolved Worker[b]	
	Dose (person-rem)	LCFs[d]	Dose (rem)	LCFs[c]	Dose (rem)	LCFs[c]
Generic Site 1 [e]	7,000	4	60	0.07	500	0.6
Generic Site 2 [f]	$2x10^4$	10	60	0.07	500	0.6
Generic Site 3 [g]	$9x10^4$	60	60	0.07	500	0.6
Generic Site 4 [h]	$1x10^4$	8	70	0.09	90	0.1
Generic Site 5 [i]	$4x10^4$	20	70	0.09	90	0.1
Generic Site 6 [j]	$2x10^5$	100	70	0.09	90	0.1

[a] 3,020 ft (920 m) from the hypothesized release
[b] 328 ft (100 m) from the hypothesized release
[c] Increased likelihood of a latent cancer fatality, calculated using the factor of 6×10^{-4} LCFs per rem, doubled for receptors exposed to doses greater than 20 rem, and truncated at 1
[d] Increased number of latent cancer fatalities, calculated using the factor of 6×10^{-4} LCFs per person-rem
[e] Large atmospheric dispersion with a population of 304,000 within 50 mi (80 km) of the site
[f] Large atmospheric dispersion with a population of 1,660,000 within 50 mi (80 km) of the site
[g] Large atmospheric dispersion with a population of 8,230,000 within 50 mi (80 km) of the site
[h] Small atmospheric dispersion with a population of 304,000 within 50 mi (80 km) of the site
[i] Small atmospheric dispersion with a population of 1,660,000 within 50 mi (80 km) of the site
[j] Small atmospheric dispersion with a population of 8,230,000 within 50 mi (80 km) of the site

Using the dose-to-risk conversion factor of 6×10^{-4} LCFs per person-rem, the collective population dose is estimated to result in a range of 4 additional LCFs to 100 additional LCFs. The MEI has a probability range of 0.07 to 0.09 of a LCF should this scenario occur. The noninvolved worker has a probability range of 0.1 to 0.6 of a LCF should this scenario occur.

B.2.2.2 *Advanced Recycling Reactors*

DOE selected a representative event to analyze with regard to potential intentional destructive acts at the advanced recycling reactor. The "Unmitigated Aircraft Crash" is the accident with the greatest impacts to all receptors. Since the "Unmitigated Aircraft Crash" could be caused by an intentional destructive act, it is selected as the intentional destructive act for analysis. Table B.2.2.2-1 presents the "Unmitigated Aircraft Crash" for the advanced recycling reactor at each site.

TABLE B.2.2.2-1—*Potential Consequences – Intentional Destructive Acts at an Advanced Recycling Reactor*

Site	Offsite Population		MEI[a]		Noninvolved Worker[b]	
	Dose (person-rem)	LCFs[d]	Dose (rem)	LCFs[c]	Dose (rem)	LCFs[c]
Generic Site 1 [e]	$6x10^5$	400	6,000	1 [k]	$8x10^4$	1 [k]
Generic Site 2 [f]	$1x10^6$	800	6,000	1 [k]	$8x10^4$	1 [k]
Generic Site 3 [g]	$7x10^6$	4,000	6,000	1 [k]	$8x10^4$	1 [k]
Generic Site 4 [h]	$3x10^6$	2,000	$5x10^4$	1 [k]	$4x10^5$	1 [k]
Generic Site 5 [i]	$5x10^6$	3,000	$5x10^4$	1 [k]	$4x10^5$	1 [k]
Generic Site 6 [j]	$2x10^7$	$1x10^4$	$5x10^4$	1 [k]	$4x10^5$	1 [k]

[a] 3,020 ft (920 m) from the hypothesized release
[b] 328 ft (100 m) from the hypothesized release
[c] Increased likelihood of a latent cancer fatality, calculated using the factor of 6×10^{-4} LCFs per rem, doubled for receptors exposed to doses greater than 20 rem, and truncated at 1
[d] Increased number of latent cancer fatalities, calculated using the factor of 6×10^{-4} LCFs per person-rem
[e] Large atmospheric dispersion with a population of 304,000 within 50 mi (80 km) of the site
[f] Large atmospheric dispersion with a population of 1,660,000 within 50 mi (80 km) of the site
[g] Large atmospheric dispersion with a population of 8,230,000 within 50 mi (80 km) of the site
[h] Small atmospheric dispersion with a population of 304,000 within 50 mi (80 km) of the site
[i] Small atmospheric dispersion with a population of 1,660,000 within 50 mi (80 km) of the site
[j] Small atmospheric dispersion with a population of 8,230,000 within 50 mi (80 km) of the site
[k] Calculated radiation dose to this individual is estimated to result in acute health effects

Using the dose-to-risk conversion factor of 6×10^{-4} LCFs per person-rem the collective population dose is estimated to result in a range of 400 to $1x10^4$ additional LCFs within the entire surrounding population. For the MEI and noninvolved worker, the calculated radiation dose to this individual is estimated to result in acute health effects (e.g., damage to the central nervous system or death).

B.2.3 Thermal/Fast Reactor Recycle Alternative

This section presents the impacts of potential intentional destructive acts associated with facilities under the Thermal/Fast Reactor Recycle Alternative. The impacts for the Thermal/Fast Reactor Recycle Alternative would be the same as the Fast Reactor Recycle Alternative, with the exception of the potential for LWR events associated with MOX-U-Pu fuel.

B.2.3.1 *Mixed Oxide-Uranium-Plutonium Fueled Light Water Reactor*

The impact of potential accidents at LWRs utilizing MOX-U-Pu fuel was evaluated for the SPD EIS (DOE 1999d). The SPD EIS evaluated accidents at three existing LWR sites utilizing conventional LWR LEU fuel, as well as cores consisting of 40 percent mixed oxide (MOX) fuel and 60 percent conventional LWR fuel. This section evaluates the LWR using the MOX-U-Pu fuel. The SPD EIS considered both design basis and beyond design basis events, both of which are considered here. While design basis events are considered, this analysis is focused on the highest consequence scenario, which is a beyond design basis event. Table B.2.3.1-1 presents the consequences for the MOX-U-Pu fueled LWR "Interfacing System LOCA," which could be caused by an intentional destructive act. Appendix D, Section D.2.3.1 "Interfacing System LOCA" provides the details of its analysis. The results presented include estimates of the incremental LCFs for each receptor at the six generic sites.

TABLE B.2.3.1-1—*Potential Consequences – Intentional Destructive Acts for a Mixed Oxide-Uranium-Plutonium Light Water Reactor*

Site	Offsite Population		MEI[a]		Noninvolved Worker[b]	
	Dose (person-rem)	LCFs[d]	Dose (rem)	LCFs[c]	Dose (rem)	LCFs[c]
Generic Site 1 [e]	$2x10^6$	1,000	$2x10^4$	1 [k]	$2x10^5$	1 [k]
Generic Site 2 [f]	$4x10^6$	2,000	$2x10^4$	1 [k]	$2x10^5$	1 [k]
Generic Site 3 [g]	$2x10^7$	$1x10^4$	$2x10^4$	1 [k]	$2x10^5$	1 [k]
Generic Site 4 [h]	$7x10^6$	4,000	$1x10^5$	1 [k]	$5x10^5$	1 [k]
Generic Site 5 [i]	$2x10^7$	9,000	$1x10^5$	1 [k]	$5x10^5$	1 [k]
Generic Site 6 [j]	$6x10^7$	$4x10^4$	$1x10^5$	1 [k]	$5x10^5$	1 [k]

[a] 3,020 ft (920 m) from the hypothesized release
[b] 328 ft (100 m) from the hypothesized release
[c] Increased likelihood of a latent cancer fatality, calculated using the factor of 6×10^{-4} LCFs per rem, doubled for receptors exposed to doses greater than 20 rem, and truncated at 1
[d] Increased number of latent cancer fatalities, calculated using the factor of 6×10^{-4} LCFs per person-rem
[e] Large atmospheric dispersion with a population of 304,000 within 50 mi (80 km) of the site
[f] Large atmospheric dispersion with a population of 1,660,000 within 50 mi (80 km) of the site
[g] Large atmospheric dispersion with a population of 8,230,000 within 50 mi (80 km) of the site
[h] Small atmospheric dispersion with a population of 304,000 within 50 mi (80 km) of the site
[i] Small atmospheric dispersion with a population of 1,660,000 within 50 mi (80 km) of the site
[j] Small atmospheric dispersion with a population of 8,230,000 within 50 mi (80 km) of the site
[k] Calculated radiation dose to this individual is estimated to result in acute health effects

Using the dose-to-risk conversion factor of 6×10^{-4} LCFs per person-rem, the collective population dose is estimated to result in a range of 1,000 to $4x10^4$ additional LCFs. For the MEI and noninvolved worker, the calculated radiation dose to this individual is estimated to result in acute health effects (e.g., damage to the central nervous system or death).

B.2.3.2 *Mixed Oxide-Uranium-Plutonium Fueled Advanced Light Water Reactor*

As discussed in Appendix D, DOE has previously analyzed accidents associated with ALWRs using LEU fuel at a variety of locations in the Tritium Supply and Recycling Final PEIS (DOE 1995b); however, DOE did not analyze the ALWR with MOX-U-Pu fuel. For this GNEP PEIS, DOE has re-analyzed those ALWR accident scenarios for LEU fuel (see Appendix D, Section D.2.3.2) for the six generic programmatic sites. The accident scenarios are not affected by the type of fissile material in the fuel, so the LEU fueled ALWR scenarios are applicable to a MOX-U-Pu fueled ALWR. A description of each LEU ALWR accident is presented in the Tritium Supply and Recycling Final PEIS (DOE 1995b).

While the scenarios are not affected by the fuel type, the consequences are affected by the fuel type. The SPD EIS (DOE 1999d) evaluated an LEU fueled LWR and a MOX-U-Pu fueled LWR and determined that the MOX-U-Pu fueled LWR impacts average about 5 percent greater than the corresponding impacts for an LEU fueled LWR with some variation from scenario to scenario. The effect different fuel types have on the impacts is expected to be similar for an LWR and an ALWR, so it is expected that a MOX-U-Pu fueled ALWR would have impacts that are about 5 percent greater on average than the impacts for an LEU fueled ALWR. The LEU fueled ALWR impacts reported in Table B.2.1.2-1 are used directly for the MOX-U-Pu fueled ALWR.

B.2.4 Thermal Reactor Recycle Alternative

This alternative includes analysis of the impacts of constructing and operating Thermal Reactor Recycle Alternative facilities, including the construction of one or more nuclear fuel recycling centers, operations to recycle SNF and produce nuclear fuel, transportation of fuel to reactors, and waste management facilities. Section B.2.2.1 presents the impacts for an "Unmitigated Aircraft Crash" (the highest consequence event), at a variety of sites, for a nuclear fuel recycling center for the Fast Recycle Alternative. This analysis is representative of the types of impacts that could result from these facilities.

This alternative includes three recycle reactor options: 1) recycle in LWRs, 2) recycle in heavy water reactors (HWRs), and 3) recycle in high-temperature gas-cooled reactors (HTGRs). Each of these three reactor types is addressed below.

B.2.4.1 *Recycle in Light Water Reactors (Option 1)*

This option involves the recycling of fuel in LWRs or ALWRs. Section B.2.3.1 addresses the impacts associated with the use of MOX-U-Pu fuel in a LWR. Section B.2.3.2 addresses the impacts associated with the use of MOX-U-Pu fuel in an ALWR. There are differences between the weapons-grade plutonium used in the SPD EIS (DOE 1999d) analysis and the transuranics that would be used under this alternative, but these differences are not expected to invalidate the conclusion that the impacts would be only slightly greater. Therefore, the impacts for recycled fuel are expected to also be approximately the same as the results for the MOX-U-Pu fueled reactors.

B.2.4.2 *Recycle in Heavy Water Reactors (Option 2)*

This option involves the recycling of fuel in HWRs. DOE has previously analyzed accidents associated with HWRs utilizing enriched uranium fuels at a variety of locations in the Tritium Supply and Recycling Final PEIS (DOE 1995b). The accidents identified in the Tritium Supply and Recycling Final PEIS (DOE 1995b) were re-analyzed for this PEIS and the results are summarized in Section B.2.6.1. Use of recycled fuel could increase the transuranic inventory and increase the consequences somewhat; however, the SPD EIS found that use of MOX-U-Pu in LWRs with its increased transuranic inventory increased risk an average of 5 percent (DOE 1999d). There are differences between the weapons-grade plutonium used in the SPD EIS (DOE 1999d) analysis and the transuranics that would be used under this alternative, but these differences are not expected to invalidate the conclusion that the impacts would be only slightly greater. Therefore, the impacts for recycled fuel, including DUPIC, are expected to also be approximately the same as the results for the uranium fueled reactors. Therefore, the results presented in Section B.2.6.1 are appropriate for recycling of fuel in an HWR.

B.2.4.3 *Recycle in High Temperature Gas-Cooled Reactors (Option 3)*

DOE has previously analyzed accidents associated with HTGRs at a variety of locations in the Tritium Supply and Recycling Final PEIS (DOE 1995b). In this PEIS, DOE has re-analyzed the consequences of the scenarios presented in DOE (1995b) and the results are summarized in

Section B.2.6.2. Use of recycled fuel could increase the transuranic inventory and increase the consequences somewhat; however, the SPD EIS found that use of MOX-U-Pu in LWRs with its increased transuranic inventory increased risk an average of 5 percent (DOE 1999d). There are differences between the weapons-grade plutonium used in the SPD EIS (DOE 1999d) analysis and the transuranics that would be used under this alternative, but these differences are not expected to invalidate the conclusion that the impacts would be only slightly greater. Therefore, the impacts for recycled fuel are expected to also be approximately the same as the results for the uranium fueled reactors. The results presented in Section B.2.6.2 are appropriate for recycling of fuel in an HTGR.

B.2.5 Thorium Alternative

As described in Section 2.4 of this PEIS, the thorium once-through fuel cycle, while different in many aspects from the existing uranium once-through fuel cycle, can be characterized as a "new fuel design" rather than a new reactor concept, because the thorium fuel cycle would be compatible with existing and future thermal reactors (e.g., LWRs, HWRs, and HTGRs). Existing and future commercial reactors (e.g., LWRs, HWRs, and HTGRs) could accept a thorium-based fuel without requiring fundamental modification. For purposes of this PEIS, the analysis of the thorium open fuel cycle is focused on LWRs since LWRs are the predominant commercial electricity producing technology that exists in the world today.

Accident analyses for two heterogeneous "seed-blanket" implementation schemes for thorium fueled LWR have been performed by Brookhaven National Laboratory and the Massachusetts Institute of Technology (Todosow and Kazimi 2004). The two concepts are the seed-blanket-unit where the seed and blanket occupy the same space as a conventional assembly, and the whole-assembly-seed-blanket where the seed and blanket rods are located in distinct assemblies. Several "bounding" accidents were evaluated, for each concept: 1) large break loss-of-coolant accident; 2) loss of primary flow; and 3) loss of offsite power. The results for safety-related parameters were comparable to those for a conventional uranium-fueled LWR. It was concluded for accidents that the consequences of the Thorium Alternative are comparable to the consequences of the LEU fueled LWR (see Section D.2.5) and this same conclusion is applied to intentional destructive acts. For other reactor types, use of thorium reactor fuel is expected to result in consequences that are comparable to the consequences for the use of LEU fuel in the same reactor. For the HWR and HTGR, the highest consequence event would be an "Unmitigated Aircraft Crash" and its consequences are reported in Section B.2.6 and they are less than the consequences for a LWR.

B.2.6 Heavy Water Reactor/High Temperature Gas-Cooled Reactor Alternative

B.2.6.1 *Heavy Water Reactors (Option 1)*

DOE has previously analyzed accidents associated with HWRs at a variety of locations in the Tritium Supply and Recycling Final PEIS (DOE 1995b). In this PEIS, DOE has re-analyzed the risks of the accident scenarios presented in the Tritium Supply and Recycling Final PEIS at the six generic sites in Appendix D. The accident with the highest consequence is the "Unmitigated Aircraft Crash," which could also be the result of an intentional destructive act. Therefore, the

"Unmitigated Aircraft Crash" is also the intentional destructive act with the highest consequence. Appendix D provides details of the consequence analysis for this event. Table B.2.6.1-1 presents the "Unmitigated Aircraft Crash" consequences for the HWR at each of these six generic sites.

TABLE B.2.6.1-1—*Potential Consequences – Intentional Destructive Acts at a Heavy Water Reactor*

Site	Offsite Population		MEI[a]		Noninvolved Worker[b]	
	Dose (person-rem)	LCFs[d]	Dose (rem)	LCFs[c]	Dose (rem)	LCFs[c]
Generic Site 1 [e]	$8x10^4$	50	900	1 [k]	$1x10^4$	1 [k]
Generic Site 2 [f]	$2x10^5$	100	900	1 [k]	$1x10^4$	1 [k]
Generic Site 3 [g]	$9x10^5$	500	900	1 [k]	$1x10^4$	1 [k]
Generic Site 4 [h]	$4x10^5$	200	7,000	1 [k]	$6x10^4$	1 [k]
Generic Site 5 [i]	$7x10^5$	400	7,000	1 [k]	$6x10^4$	1 [k]
Generic Site 6 [j]	$3x10^6$	2,000	7,000	1 [k]	$6x10^4$	1 [k]

[a] 3,020 ft (920 m) from the hypothesized release.
[b] 328 ft (100 m) from the hypothesized release.
[c] Increased likelihood of a latent cancer fatality, calculated using the factor of 6×10^{-4} LCFs per rem and doubled for receptors exposed to doses greater than 20 rem and truncated at 1.
[d] Increased number of latent cancer fatalities, calculated using the factor of 6×10^{-4} LCFs per person-rem.
[e] Large atmospheric dispersion with a population of 304,000 within 50 mi (80 km) of the site
[f] Large atmospheric dispersion with a population of 1,660,000 within 50 mi (80 km) of the site
[g] Large atmospheric dispersion with a population of 8,230,000 within 50 mi (80 km) of the site
[h] Small atmospheric dispersion with a population of 304,000 within 50 mi (80 km) of the site
[i] Small atmospheric dispersion with a population of 1,660,000 within 50 mi (80 km) of the site
[j] Small atmospheric dispersion with a population of 8,230,000 within 50 mi (80 km) of the site
[k] Calculated radiation dose to this individual is estimated to result in acute health effects

Using the dose-to-risk conversion factor of 6×10^{-4} LCFs per person-rem the collective population dose is estimated to result in a range of 50 additional LCFs to 2,000 additional LCFs. For the MEI and noninvolved worker, the calculated radiation dose to this individual is estimated to result in acute health effects (e.g., internal bleeding, damage to the central nervous system, or death).

B.2.6.2 *High Temperature Gas-Cooled Reactors (Option 2)*

DOE has previously analyzed accidents associated with HTGRs at a variety of locations in the Tritium Supply and Recycling Final PEIS (DOE 1995b). In this PEIS, DOE has re-analyzed the risks of the accident scenarios presented in the Tritium Supply and Recycling Final PEIS at the six generic sites. The accident with the highest consequence is the "Unmitigated Aircraft Crash," which could also be the result of an intentional destructive act. Therefore, the "Unmitigated Aircraft Crash" is also the intentional destructive act with the highest consequence. Appendix D provides details of the consequence analysis for this event. Table B.2.6.2-1 presents the consequences for the HTGR "Unmitigated Aircraft Crash" at each of these six generic sites.

TABLE B.2.6.2-1—*Potential Consequences – Intentional Destructive Acts at a High Temperature Gas-Cooled Reactor*

Site	Offsite Population		MEI[a]		Noninvolved Worker[b]	
	Dose (person-rem)	LCFs[d]	Dose (rem)	LCFs[c]	Dose (rem)	LCFs[c]
Generic Site 1 [e]	$4x10^4$	20	400	0.5	5,000	1 [k]
Generic Site 2 [f]	$9x10^4$	50	400	0.5	5,000	1 [k]
Generic Site 3 [g]	$4x10^5$	200	400	0.5	5,000	1 [k]
Generic Site 4 [h]	$2x10^5$	100	3,000	1 [k]	$3x10^4$	1 [k]
Generic Site 5 [i]	$3x10^5$	200	3,000	1 [k]	$3x10^4$	1 [k]
Generic Site 6 [j]	$1x10^6$	800	3,000	1 [k]	$3x10^4$	1 [k]

[a] 3,020 ft (920 m) from the hypothesized release.
[b] 328 ft (100 m) from the hypothesized release.
[c] Increased likelihood of a latent cancer fatality, calculated using the factor of $6×10^{-4}$ LCFs per rem, doubled for receptors exposed to doses greater than 20 rem, and truncated at 1.
[d] Increased number of latent cancer fatalities, calculated using the factor of $6×10^{-4}$ LCFs per person-rem.
[e] Large atmospheric dispersion with a population of 304,000 within 50 mi (80 km) of the site
[f] Large atmospheric dispersion with a population of 1,660,000 within 50 mi (80 km) of the site
[g] Large atmospheric dispersion with a population of 8,230,000 within 50 mi (80 km) of the site
[h] Small atmospheric dispersion with a population of 304,000 within 50 mi (80 km) of the site
[i] Small atmospheric dispersion with a population of 1,660,000 within 50 mi (80 km) of the site
[j] Small atmospheric dispersion with a population of 8,230,000 within 50 mi (80 km) of the site
[k] Calculated radiation dose to this individual is estimated to result in acute health effects

Using the dose-to-risk conversion factor of $6×10^{-4}$ LCFs per person-rem the collective population dose is estimated to result in a range of 50 additional LCFs to 800 additional LCFs. For the MEI, the calculated radiation dose to this individual is estimated to result in a likelihood of 0.5 (Sites 1 thorough 3) to acute health effects (Sites 4 through 6) of an LCF. For the noninvolved worker, the calculated radiation dose to this individual is estimated to result in acute health effects (e.g., damage to the central nervous system or death).

B.3 NUCLEAR MATERIALS TRANSPORTATION

B.3.1 Methodology

For potential intentional destructive acts associated with transportation of nuclear materials, DOE has chosen to analyze events associated with transportation of LWR SNF. The LWR SNF was selected for analysis because it is the risk dominant fuel. While the impacts from the MOX-U-Pu SNF are higher than for the LEU LWR SNF, the number of LEU LWR shipments is much greater so its risks are greater. For this analysis, DOE is incorporating the analysis presented in the *Supplemental Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada* (DOE 2008f) and its supporting calculation package (BMI 2007). Appendix E (see Table E.2.5-12) provides the maximum reasonably foreseeable transportation accidents for all SNF and high-level radioactive waste associated with the GNEP operations without intentional destructive acts. While the Appendix E values are not directly comparable to the results of this section, they do provide a basis for relative comparison of the potential waste form impacts.

DOE used the following assumptions to estimate the consequence of transportation sabotage events (Jason Technologies 2001):

- A breathing rate for individuals of 367,272.5 cubic feet (ft^3) per year (10,400 cubic meters [m^3] per year) (5.23 gallons [gal] per minute [19.8 liters {L} per minute]). This breathing rate was estimated from data contained in *International Commission on Radiological Protection* (ICRP) Publication 23 (ICRP 1975).
- A short-term exposure time to airborne contaminants of 2 hours.
- A long-term exposure time to contamination deposited on the ground of 1 year, with no interdiction.
- Because it is not possible to estimate the specific atmospheric conditions that would exist during a sabotage event, consequences were determined using moderate wind speeds and neutral atmospheric conditions (a wind speed of 14.67 ft per second [4.47 m per second] and Class D stability).
- The release of both respirable and nonrespirable material was evaluated. The deposition velocity for respirable material was 0.03 ft per second (0.01 m per second). The deposition velocity for nonrespirable material was 0.3 ft per second (0.1 meter per second).
- It is expected that in a sabotage event, there would be an initial explosive release involving releases of radioactive material at varying release heights. For 4 percent of the release, a release height of 3 ft (1 m) was estimated; for 16 percent of the release, a release height of 52 ft (16 m) was estimated; for 25 percent of the release, a release height of 105 ft (32 m) was estimated; for 35 percent of the release, a release height of 157 ft (48 m) was estimated; and for 20 percent of the release, a release height of 210 ft (64 m) was estimated.

DOE plans to operate the repository using a primarily canistered approach that calls for packaging most commercial SNF in transportation, aging and disposal canisters (TAD), which would hold 21 PWR SNF assemblies. However, no credit was taken for the TAD. The TAD will be shipped inside a cask. The shipment configuration is similar to the rail shipment configuration assumed in Appendix E. The radionuclide inventory for a single SNF assembly in this cask is listed in Table B.3.1-1. Appendix E, Section E.2.2.1 describes the shipment of spent fuel, including fresh and spent fast reactor fuel. Shipment of other wastes is discussed in Appendix E, Section E.2.2.2.

DOE evaluated the consequences of sabotage events using previously published release fraction data (Luna et al. 1999, DOE 2002i). For rail casks, a sabotage event using the high energy density device (HEDD1) yielded the largest radiation doses. Additional data from sabotage experiments conducted in Germany were used by DOE to update the release fractions for HEDD1 (Luna 2006) used to estimate the consequences of sabotage events in the *Final Supplemental Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada – Nevada Rail Transportation Corridor and the Final Environmental Impact Statement for a Rail Alignment for the Construction and Operation of a Railroad in Nevada to a Geologic Repository at Yucca Mountain, Nye County, Nevada (Rail Alignment EIS)* (DOE 2008g). Table B.3.1-2 lists these release fractions.

TABLE B.3.1-1—*Radionuclide Inventories for Commercial Spent Nuclear Fuel Shipped in Rail Casks* [a]

Radionuclide	Pressurized water reactor commercial spent nuclear fuel assembly inventory (Ci) [b]	Pressurized water reactor commercial spent nuclear fuel total inventory (Ci) [b]	Boiling water reactor commercial spent nuclear fuel assembly inventory (Ci) [c]	Boiling water reactor commercial spent nuclear fuel total inventory (Ci) [c]
Am-241	1,280	1.11×10^{8}	373	4.61×10^{7}
Am-242m	7.99	6.96×10^{5}	2.88	3.56×10^{5}
Am-243	39.3	3.42×10^{6}	8.63	1.07×10^{6}
C-14	0.435	3.79×10^{4}	0.169	2.09×10^{4}
Cd-113m	23.4	2.03×10^{6}	6.23	7.69×10^{5}
Ce-144	69.9	6.09×10^{6}	17.3	2.14×10^{6}
Cm-242	6.60	5.75×10^{5}	2.38	2.94×10^{5}
Cm-243	24.8	2.16×10^{6}	5.55	6.86×10^{5}
Cm-244	5,850	5.09×10^{8}	923	1.14×10^{8}
Cm-245	0.816	7.10×10^{4}	0.0907	1.12×10^{4}
Cm-246	0.407	3.54×10^{4}	0.0426	5,260
Co-60	2,170	1.89×10^{8}	114	1.41×10^{7}
Co-60	(Crud) [d]	16.9	1.47×10^{6}	56.6
Cs-134	5,430	4.73×10^{8}	1,310	1.62×10^{8}
Cs-137	7.16×10^{4}	6.23×10^{9}	$2.41\text{x}10^{4}$	2.98×10^{9}
Eu-154	3,010	2.62×10^{8}	779	9.62×10^{7}
Eu-155	642	5.59×10^{7}	193	2.39×10^{7}
Fe-55	(Crud) [d]	209	1.82×10^{7}	98.4
H-3	305	2.66×10^{7}	105	1.30×10^{7}
I-129	0.0276	2,400	0.00922	1,140
Kr-85	3,390	2.95×10^{8}	1,170	1.45×10^{8}
Np-237	0.294	2.56×10^{4}	0.0874	1.08×10^{4}
Pm-147	6,060	5.28×10^{8}	2,110	2.61×10^{8}
Pu-238	3,980	3.46×10^{8}	1,020	1.26×10^{8}
Pu-239	175	1.52×10^{7}	54.1	6.68×10^{6}
Pu-240	363	3.16×10^{7}	127	1.57×10^{7}
Pu-241	5.64×10^{4}	4.91×10^{9}	1.57×10^{4}	1.94×10^{9}
Pu-242	2.48	2.16×10^{5}	0.708	8.75×10^{4}
Ru-106	404	3.52×10^{7}	90.5	1.12×10^{7}
Sb-125	520	4.53×10^{7}	145	1.79×10^{7}
Sr-90	4.51×10^{4}	3.93×10^{9}	1.66×10^{4}	2.05×10^{9}
U-232	0.0361	3,140	0.00874	1,080
U-234	0.524	4.56×10^{4}	0.239	2.95×10^{4}
U-236	0.177	1.54×10^{4}	0.0745	9,200
U-238	0.146	1.27×10^{4}	0.0624	7,710
Y-90	4.51×10^{4}	3.93×10^{9}	1.66×10^{4}	2.05×10^{9}

[a] Sources: BSC 2004, BSC 2003
[b] Total inventory for pressurized water reactor spent nuclear fuel shipped in rail casks is based on 87,057 assemblies (calculated from rail shipments and cask capacities from BSC 2007
[c] Total inventory for boiling water reactor spent nuclear fuel shipped in rail casks is based on 123,537 assemblies (calculated from rail shipments and cask capacities from BSC 2007
[d] Chalk River Unknown Deposit (CRUD) (generic term for various residues deposited on fuel rod surfaces, originally coined by Atomic Energy of Canada, Ltd. (AECL) to describe deposits observed on fuel removed from the test reactor at Chalk River)

TABLE B.3.1-2—*Release Fractions for Transportation Sabotage Event* [a]

Material	Release Fraction					
	Particulates	Ruthenium [b]	Cesium [c]	Iodine [c]	Gas	Crud
Respirable	7.19×10^{-7}	7.19×10^{-7}	7.15×10^{-6} [d]	7.15×10^{-6} [d]	4.05×10^{-4} [d]	5.17×10^{-7}
Nonrespirable	1.75×10^{-4}	1.75×10^{-4}				5.16×10^{-8}

[a] Source: Luna 2006
[b] Ruthenium is modeled as particulate
[c] Cesium and iodine are modeled as volatiles
[d] All cesium, iodine, and gases were assumed to be respirable

Radiation doses for the sabotage event scenario were estimated using the RISKIND (Radioactive Waste Transport Risk Code) computer code (Yuan et al. 1995). RISKIND has been verified for estimating radiation doses from releases of radioactive material during transportation (Maheras and Pippen 1995, Biwer et al. 1997). Radiation doses were determined for the inhalation, groundshine, immersion, and resuspension pathways. Radiation doses were estimated using the ICRP inhalation dose coefficients (ICRP 2001) and the EPA groundshine and immersion dose coefficients (EPA 2002a). These dose coefficients are based on the recommendations in the ICRP Publication 60 (ICRP 1991) and incorporate the dose coefficients from ICRP Publication 72 (ICRP 1996).

B.3.2 Results

Table B.3.2-1 lists the consequences of a potential sabotage event. The MEI would be located 330 ft (100 m) from the sabotage event, at the location of maximum downwind air concentration. The radiation dose for the MEI is estimated to be 27 rem. Using the dose-to-risk conversion factor of twice 6×10^{-4} per person-rem for individual doses greater than 20 rem, the MEI dose has a increased likelihood of 0.032 (or 1 chance in 31of a LCF).

TABLE B.3.2-1—*Consequences of a Radiological Transportation Sabotage Event* [a]

Maximally exposed individual (rem)	27
Latent cancer fatality [b]	0.032

[a] Consequences based on moderate wind speeds and neutral atmospheric conditions
[b] Increased likelihood of a latent cancer fatality

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